AN ELECTRO-CHEMICAL THEORY OF NORMAL AND CERTAIN PATHOLOGICAL PROCESSES.

By G. W. CRILE, M.D.

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That electro-chemical processes play an important rôle in living processes has long been held by bio-chemists and bio-physicists.

Du Bois Reymond held that the action current is an electric current; and Crehore and Williams have put forward strong evidence in favor of the identity of the action current and electricty.

Burdon Sanderson demonstrated that motor plants such as venus' fly trap and the sensitive plant show electric variations during their specific response to stimulation. Waller extended these observations and called these electric variations "blaze currents of action." Bose has found evidence of the identity of vegetable and animal activity, and having demonstrated by most ingenious experiments that the activities of plants are attended by electrical phenomena he concludes that electricity plays an important rôle in vital phenomena.

Piper showed that sound waves originate an electric current in the auditory nerve of fish; and Einthoven and Jolly confirmed the discovery made by Holmgren in 1866 that when light falls on the retina, an electric current is produced in the optic nerve.

Gotch and Horsley have shown that during electric stimulation of the cortex, causing muscular action of the leg, a sustained electromotive force is present in the spinal cord during the continuance of the stimulation. Not only did they demonstrate an electric wave, but they were able to pick out the conduction paths in the spinal cord over which this wave travelled, showing that the current found its way along the intricate pathway from the cortex to the muscles, passing over the various synapses with accuracy. Gotch and Horsley also demonstrated a persistent negative variation in the cord during electric stimulation of the Rolandic area.

Nernst supposed that the electrolytes in the axis cylinder lie within membranes which are impermeable to certain ions; and that when an electric current is passed through a nerve, it is conveyed by the dissociated electrolytes, causing an accumulation of positive ions at one point and of negative ions at another: when the concentration reaches a certain point, excitation occurs. A. V. Hill supports Nernst's general theory; and McClendon, Bayliss, Lillie and others take a similar view. Lillie has developed an analogy between the local electrical effects in metals and in living tissue, as exemplified by the passive state in metals and in nerve conduction. He considers that the phenomena in each case are due to the formation of local electrical currents, resulting in the case of metals from local changes in surface tension; and in nerve tissue from local changes in the permeability of the surface film or membrane. In each case the phenomena are subject to rapid "spreading" as a result of electrical polarization, the rate of "spreading" depending upon the rate of the reaction which initiates it. He states that in nerve tissue "a relation of direct proportion should thus exist between the electric conductivity of the medium and the rate of propagation of the excitation wave."

By microchemical methods MacCallum showed that since it contains a greater concentration of electrolytes, the axis cylinder is a better conductor than the medullary sheath.

Meyer found that alteration in the concentration of electrolytes in the seawater in which the nerve of a marine animal was suspended altered equally the rate of electric conductivity of the water and the rate of nerve conduction.

Tashiro has demonstrated that as the result of the passage of the normal action current down a nerve fiber, carbon dioxid is given off and oxygen is consumed. He has shown also that when a nerve is stimulated by electricity, the same phenomena are observed; *i.e.*, carbon dioxid is given off and oxygen is consumed. Moreover, whether in the case of the normal or of the eletcrical current, no heat is produced. A. V. Hill has confirmed Tashiro's findings as to the absence of heat; and Benedict was unable to demonstrate heat resulting from mental activity.

Following the lead offered by the above-cited investigators and by

many other bio-physicists, we propose to offer further evidence in support of the hypothesis that man is an electro-chemical mechanism, as gained, first, from a general consideration of the structure and arrangement of the central nervous system; second, from laboratory findings; and third, from observations and experience in the clinic.

Structure and Arrangement of the Central Nervous System.

The nerve cell consists of two highly differentiated parts, the nucleus and the cell body, which are separated from each other by a semi-permeable membrane. Sir Frederick Mott has shown that the so-called Nissl bodies during life are globules covered by a lipoid film on which oxidation occurs. The nucleus and the cell-body cannot be sharply stained with the same stain, but differential stains are required. This fact indicates a difference between the composition and function of these two parts of the cell. Two colloidal solutions, one acid and the other neutral or alkaline, separated by a semi-permeable membrane, constitute a battery. The nerve cell, therefore, is a battery. Electricity travels from areas of higher to areas of lower potential. In the animal organism the nerve-cell batteries are connected by microscopically fine prolongations of the nerve cells. Constant discharge of the artificial electric battery used in the laboratory is prevented by "make and break" *keys;* constant discharge of the nerve-cell battery is prevented by a "make and break" mechanism called a *synapse.*

According to this hypothesis, the unit structure of animals consists of a *nerve-cell battery* (or electric cell), its prolongation or *nerve fiber* to the *synapse* or key, the connecting *nerve fiber* from the synapse to the muscle cell or gland, by whose discharge upon receipt of an electric current from the nerve-cell battery, action is effected. Electricity alone can close the synoptic "key," complete the circuit and fire the "charge."

General and Laboratory Observations of the Electro-Chemical Reactions of the Organism.

If we are correct in assuming that each nerve-muscle and each nerve-gland unit is a part of a biologic electro-chemical system, all of which collectively make up the organism, then we would expect

that the nerve-cell battery like other batteries could not create electricity continuously, but would require periods of rest for recharging. These periods of discharging and of recharging are respectively periods of consciousness and of sleep. We know that fatigue and death result from prolonged deprivation of sleep. The changes within the brain and the liver cells are evidenced by swelling; by a striking diminution of differential stainability and, as we shall show later, by changes in their electric conductivity. We would expect that the fatigue (weariness) produced by activity would be restored by sleep. That this is so is shown by common experience and by histologic and conductivity findings.

The principal parts of the cell are (*a*) water; (*b*) salts in solution; (*c*) selective semi-permeable membranes.

Water.—Life is coextensive with water; water is the vehicle in which life is suspended. Perhaps the strongest evidence in favor of the electro-chemical theory may be found in a consideration of the properties of water. Of highest significance is the fact that water is a non-conductor of electricity. This property is essential for the accumulation of electric charges; it is essential for the formation of colloids. Colloids are essential to life. Water is the greatest solvent. Water is the greatest catalyst, hence water is the vehicle best adapted for the storage of energy. Suspensions and solutions are electrical processes. We have therefore as the physical basis of every cell a non-conducting medium in which are suspended electrically charged particles. In free colloids or in solutions, the electric energy is evenly diffused. To create, to store, and to discharge energy for adaptive purposes, an additional structure is required. This structure consists of the lipoid selective semi-permeable membranes surrounding the cell as a whole, surrounding the nucleus, and surrounding the spherules lying in the layer compartments. Why were the membranes evolved to be selective semi-permeable membranes? So that oxygen and activating agents may enter, in order that potential energy may be created within the cell; and that there may be a suitable riddance of damaging compounds.

The activity of the nerve cell is dependent in large measure upon oxidation. We would expect that the energy of the cells

would be destroyed should the water in the cells become and remain saturated with acid salts, so that the essential difference of potential between the nucleus and the cell body would be lost; and that this would happen unless continuity of the supply of fresh water is assured. We know that life ends within a few days when the body takes in no fresh water.

We would expect that the electric impulse could reach and move the muscle only if the conductivity of the conducting paths—axis cylinders, spinal cord—were greater than the conductivity of the brain, and the conductivity of the muscles greater than the conductivity of the nerves. This point has been tested in 436 animals and in every instance, in animals which were conscious at the time of their death, the conductivity of the spinal cord was greater than that of the brain; the conductivity of the muscles was greater than that of the spinal cord.

We would expect to find that the greatest activity of the organism is coincident with the highest conductivity of the brain, the spinal cord and the muscle. Under conditions of heightened activity produced by artificially induced iodism we found the conductivity of the brain, the spinal cord, and the muscles and of other organs and tissues to be markedly increased above the normal. Likewise, the immediate effect of the injection of adrenalin was an increase in the conductivity of the brain. Likewise, the first effect of physical injury, of emotional excitation, of the injection of toxins is an immediate increase in the conductivity of the brain. Direct measurements of the temperature of the brain after the injection of adrenalin demonstrated increased activity evidenced by a rise in temperature. Conversely, one would expect that decreased oxidation would be attended by decreased conductivity and by decreased activity of the nerve cells. We found that the temperature of the brain was diminished after adrenalectomy, after hepatectomy, by hemorrhage.

In accordance with the electro-chemical theory we would expect that bodily activity would be reduced by diminishing the difference in potential in the cells. This is evidenced by the effects of the direct production of acidosis by the injection of acid, or of acidosis resulting from any excessive activity such as prolonged or extreme

exertion, intense emotion, etc. That the difference in potential between the nucleus and the cell body is decreased or destroyed in such cases is revealed by the microscope; and apparently by conductivity measurements.

Since the activity of the organism must change to meet the varying demands of the internal and of the external environment, we would expect to find created within the organism a substance or substances to increase activity, and that the production of these secretions would be controlled by the nervous system, so that the control of varying conditions of activation of the organism may be automatic. The adrenals control oxidation; the thyroid by controlling electric conductivity governs the rate of metabolism, and these organs are controlled by the nervous system.

Since the activity of the organism is accompanied by the production of acid by-products, we would expect the presence in the organism of an organ whose prime function would be the neutralization of acids to avoid their accumulation within the cell batteries with a consequent destruction of the acid-alkali balance. This is the prime function of the liver.

We would expect the organism to be depressed by interference with the physical structure of the cell, especially with the semi-permeable membranes. That this is the case is strikingly demonstrated by the effects of ether anesthesia. That ether changes permeability has been demonstrated by many physical-chemists. (McClendon, Osterhout, Lillie, Loeb, etc.)

The effect of heat and cold upon the organism is apparently in harmony with the electro-chemical theory.

Clinical Evidence.

In the surgical clinic every degree of imperfection, injury, and impairment of the organism is under observation. If our conception that man is an electro-chemical mechanism is correct, the organism should respond to methods of protection and of restoration which are based upon the laws of physics and of chemistry.

The electro-chemical theory should explain the action and gauge the safe application of anesthetics; it should indicate the paramount value of sleep as the only final means of recharging the

batteries; it should warn the clinician of the prime necessity of regulating the activity of the thyroid and of guarding the integrity of the liver and of the adrenals as essential to the maintenance of the integrity of the brain cells, and it should suggest the importance of assuring an adequate supply of oxygen for the maintenance of the internal respiration; it should emphasize the need of an unfailing continuous supply of fresh water; it should lead the clinician to protect his patient against the external influences which drive the organism excessively and consequently impair the electric cells.

For the past two years the measures employed in the Lakeside clinic have been based upon this conception, and in accordance therewith, we have adopted five main principles as our guide in the protection and restoration of our patients:

1. The organism needs an abundant supply of fresh water.

2. There must be an abundant supply of oxygen delivered to the cells for the maintenance of the internal respiration.

3. The temperature, both local and general, must be kept at or near the normal.

4. An abundance of mental and physical rest and an abundance of sleep are essential.

5. The physical structure of the cells must not be impaired by the trauma of the operation or by the anesthetic.

By the application of these measures the two essential factors in the maintenance of an electro-chemical system are assured, provided disintegration has not progressed too far for restoration to be possible; that is, the acid-alkali balance of the cells is maintained or restored and their internal respiration is protected.

As our application of these principles has extended with our increasing knowledge of the laws upon which they are based, the mortality rate in our clinic has been diminished correspondingly, and operability has been extended.

The findings of the laboratory and the everyday experience in the crucible of the clinic are in harmony with the theory that the organism of man and animals is an electro-chemical mechanism.